Experiment Plan
(Status 1 June 1999)

Site Selection

Test sites of 3km x 3km will be selected in June 1999 to represent the desired chronosequence (1 year, 2-3 years, 8-15 years, and +20 years since last fire). Mark Sofronov and Alexandra Volokitina of the Sukachev Institute of Forest Research will preliminarily identify sites. These selections will be based on discussions with local forest rangers and site surveys. Final site selection will be made by both NASA GSFC and Sukachev personnel and will be based on homogeneity of species, accessibility, and logistical constraints. All study sites will have undergone the same fire intensity and will have begun regrowth at approximately the same time after the fire (1 to 2 years ideally). For each age class, at least one replicate site will be selected. An open field area near each study site will also be identified for reference measurements of radiation. Once Landsat 7 ETM+ images become available, they will be investigated to ensure homogeneity exists within each test site.

Segment I - Ground LAI Measurements

A. Indirect Sampling of LAI

Goals

- Production of LAI validation data sets for EOS objectives

Instrumentation/material

- 2 (or 3) Li-Cor LAI-2000 Plant Canopy Analyzers (PCA):
  - 1 instrument as reference instrument, positioned in a clear cut area near the sampling area. The clear cut area will be large enough to not block any irradiance.
  - 1 (or 2) instruments for taking the actual measurements
- 1 TRAC instrument
- 1 photographic camera with fish-eye lens
- 1 GPS unit, Trimble GeoExplorer II (non-differential mode)
- 1 generator
- 1 compass
- 1 angle measurement instrument
- Spherical densiometer
- Prism

- Clinometer
- 1 tripod for mounting the photo-camera
- 1 tripod for mounting the reference LAI-2000 PCA
- 1 laptop computer for data storage
- Flag and plastic band material to mark measurement area and points
- Paint for weather-resistant marking of measurement area

Sampling Design

The sampling design for LAI will be a nested cluster. At each site that represents one of the four post-fire stand ages, 10 plots will be selected in an area of 3 km x 3 km in such a way that the maximum variation of LAI is captured. The selection of the plots will be based on field reconnaissance and remote sensing data. In 8 of the 10 plots LAI-2000 measurements will be taken at 6 locations along with hemispherical photographs (Fig. 1). In addition, TRAC data will be collected along two transects of 25 m length each. With a walking pace of 1m per 3 s and an instrument sampling frequency of 32Hz, the TRAC measurement interval will be about 10mm.

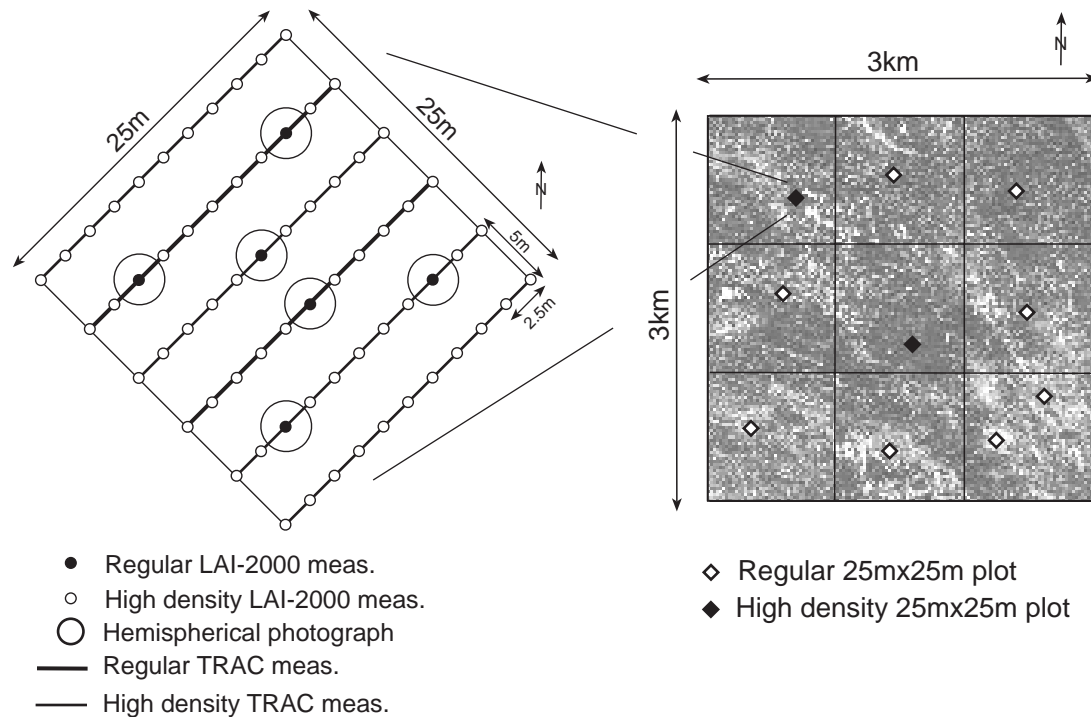plot level (25m x 25m)   site level (3km x 3km)

- ● Regular LAI-2000 meas.
- ○ High density LAI-2000 meas.
- ◯ Hemispherical photograph
- ▬ Regular TRAC meas.
- ▬ High density TRAC meas.

- ◇ Regular 25mx25m plot
- ◆ High density 25mx25m plot

Fig. 1: *Sampling design for LAI-2000 and TRAC measurements and hemispherical photographs.*

In 2 plots per site, LAI will be sampled at a very high density with LAI-2000 and TRAC instruments (Fig. 1). LAI-2000 measurements will be taken every 2.5m along six transects that are 25m long and 5m apart. TRAC measurements will be taken along the same transects with a

sampling frequency of 32Hz. Aggregating these multiple plots will capture micro- and large-scale variations in LAI at each site. Each site will be replicated once.

The transects will be oriented in SE-NW or SW-NE direction in order to reduce the influence of shadow from the operator on the TRAC and LAI-2000 instruments during data acquisition. LAI-2000 measurements will be taken consecutively from both canopy and understory levels at approximately the same measurement positions.

Synchronization of Measurements

Reference and field measurements with the LAI-2000 instruments will be taken quasi-simultaneously. The synchronization of the measurements will be guaranteed by internal clocks.

Measurement Conditions

LAI-2000 PCA measurements and hemispherical photographs will be taken during dusk or under overcast skies, i.e. under predominantly diffuse irradiance conditions. TRAC data will be acquired under bright and clear sky conditions.

Geographical Referencing

Each of the 25m x 25m plots will be geographically referenced as precisely as possible. Since it is likely that differential GPS will not be available, measurements with the Trimble GeoExplorer II will be averaged over several minutes to best approximate the coordinates of the four corners of each plot.

Determination of LAI

LAI will be determined following a technique recommended by Chen et al. (1997):

$$LAI = (1-\alpha)L_e\gamma_E / \Omega_E$$

where LAI is the leaf area index, L_e is the effective leaf area index, γ_E is needle-to-shoot area ratio, Ω_E is a factor describing foliage clumping for scales larger than the shoot, and α is the woody-to-total area ratio.

L_e will be measured with the LAI-2000 PCA instrument and Ω_E will be provided by the TRAC instrument. α and γ_E, however, will be obtained through the destructive sampling techniques, which are described in Section IB.

Derivation of FPAR

The fraction of photosynthetically active radiation (FPAR) absorbed by the canopy will be quantified with the TRAC measurements (Chen, 1996b). TRAC provides the mean value of the transmitted light through the canopy, which is directly related to FPAR (Chen, 1996b):

$$F_g(\theta) = (1 - \rho_1(\theta) - (1 - \rho_2(\theta)) \exp[-G_t(\theta)L_{eg} / \cos\theta]$$

where $F_g(\theta)$ is the FPAR due to green leaves (green FPAR), $\rho_1(\theta)$, $\rho_2(\theta)$, and $G_t(\theta)$ are species specific constants, L_{eg} is the effective green LAI, and θ is the view angle.

Understory Spectral Reflectance Measurements

Multiple spectroradiometric measurements of each dominant understory species (shrubs, herbaceous species (including grasses), and mosses) will be acquired with two radiometers: an ASD FieldSpec (400-2500nm spectral range) and an ASD PS-2 (400-1000nm spectral range). Both instruments will be borrowed from the Biospheric Sciences Branch at NASA GSFC. A reflectance reference panel with known BRDF characteristics will be used to quantify irradiance conditions. Viewing-illumination geometry will be noted in order to account for surface BRDF effects and to correct the non-Lambertian characteristics of the reference panel. Spectroradiometric data will be most valuable for specifying the NDVI characteristics of the canopy understory, which often cannot be obtained from remote sensing data.

Schedule and Test Sites

Two fir/spruce chronosequences (one test and one replicate) located within the area of one LANDSAT TM scene centered at 57.3°N / 91.3°E (path 144, row 20) will be measured during the growing season of 1999. The two youngest chronosequence stages will be revisited in 2000.

Two larch chronosequences (one test and one replicate) located within the area of one LANDSAT TM scene centered at 56°N / 87.5°E (path 146, row 21) will be measured in the growing season in 2000.

B. Destructive Sampling of LAI

Goals

•   Acquire LAI from direct sampling methods for verification of LAI data sets obtained from indirect (optical) measurements

Instrumentation / Material

•   Electronic balance
•   Field scale for large size weighing

- Various field tools including saws, trowels, clippers, lopers
- Ladders
- Rope, cording
- Tape measure (50-m length)
- Sample storage bags
- Laboratory stand for volume displacement method
- Laboratory beaker (1 L)
- Detergent
- Camera
- Long tweezers (2)
- White background
- Small ruler

Sampling design

We will sample 3-6 trees immediately adjacent to one of the 25m x 25m plots for each study site (3km x 3km area). The plot selected for destructive sampling within each study site will be chosen based on the results of the indirect LAI measurements. This will ensure that destructive sampling occurs in an area that is most characteristic of the site as a whole. We will sample 1-2 trees of the dominant, co-dominant, and suppressed species; the number sampled will be dependent upon the diversity in tree sizes found across the site. Allometric equations will be developed and applied to achieve site-level LAI.

Data Acquisition

Procedures will follow those described by Gower et al. (1997). For each tree that is destructively sampled, the crown will be divided equally into thirds with all live and dead branches at each position weighed separately. One live branch per canopy position will be chosen for detailed analyses that will be conducted immediately after felling of the tree. Shoots will be divided into age classes (current, 1-2 years, 3-4 years and >5 years) and counted. Roughly 30-50 foliage shoots per age class and canopy position will be weighed to determine fresh mass. From each subsample, 5-10 shoots will be measured for specific leaf area (leaf area/mass) and percent moisture (water content) of the leaf and woody tissues. Specific leaf area will be calculated following the volume displacement method (Chen et al. 1997). The needle surface area for each age class and canopy position will be determined by taking the product of foliage mass and specific leaf area. For each age class and canopy position, photographs of shoots against a white background will be taken at a variety of view angles for a permanent record of shoot architecture and area. The ratio of woody (nongreen) to total area (green and nongreen areas), α, will be obtained (Chen 1996a, 1996b). The needle to projected shoot area ratio, γ_E, will also be determined (Chen 1996b). Within each plot, stem density will be measured, and all trees will be sampled for diameter at breast height.

C. Analysis and Evaluation

Goals

- Production of LAI maps for each 3km x 3km test site by spatial interpolation of ground LAI measurements ('kriging')
- Comparison between LAI measurements from direct and indirect (optical) sampling methods
- Characterization of the relationship between ground-measured LAI and post-fire forest age

Scientific Questions

- How well do LAI-2000 PCA and direct LAI measurements correspond?
- How well do LAI-2000 PCA and LAI data derived from hemispherical photographs correspond?
- What is the mean LAI for each plot and each test site?
- What is the variability of LAI on the plot level (25m x 25m) for each test site?
- What is the variability of LAI on the site level (3km x 3km) (derived from the five plots per site and replicates)?
- What is the relationship between ground LAI measurements and post-fire forest age?

Optical Measurement of LAI: LAI-2000 and TRAC measurements will be resampled to a raster of 1-m resolution using kriging methods. Contour maps of each individual plot will be made to investigate the spatial distribution of LAI on the plot level (25m x 25m). Statistical measures and variograms will be used for representing the spatial pattern of LAI. Hemispherical photographs will be digitally stored on photo CDs and analyzed with the LAICALC software (Rich et al., 1995). The LAI values derived from the photographs will be overlaid to the resampled data from LAI-2000 and TRAC measurements for verification and comparison reasons. Mean and standard deviation of LAI on the plot level will be used as ground reference information in Segment II for LANDSAT TM data and in Segment III for verifying the LAI output from the Biome-BGC model.

The average LAI for all of the plots within the 3km x 3km site area will be used along with kriging techniques to generate the spatial distribution of LAI on the site level. Mean and standard deviation of LAI for the site will be used as ground reference information for remote sensing data in Segment II.

Direct Measurement of LAI: Allometric equations derived from destructive sampling will be used to extrapolate LAI from the tree to the plot and site level. Plot level and site level estimates of LAI will be compared to the resampled optical measurements of LAI (Segment IA) and to the LAI simulated by Biome-BGC (Segment III). Direct measurements of LAI will also be used as ground reference data for remote sensing data.

Post-fire Stand Age: The relationship between LAI and post-fire stand age will be determined for both optical and direct measurements of LAI. The average LAI for each stand age will be compared.

Segment II - Remote Sensing

A. Conventional Methodologies

Goals

- Establish the relationship between NDVI and LAI for Siberian boreal forests
- Investigate the 'up-scaling' of LAI products to compare ground to satellite data

Scientific Questions

- How well do ground LAI and remotely sensed LAI data correspond?
- Do LAI data derived from TM and aggregated to the spatial resolution of MODIS correspond to the LAI data derived from MODIS?
- How much information is lost by aggregating satellite data from a spatial resolution of 30m (TM) to 1km (MODIS) pixel size?

Data

- 2 TM scenes will be acquired under cloud-free and clear-sky conditions between June and August both in 1999 and 2000 for the fir/spruce and for the larch chronosequences (1 scene per species type)
- 1 MODIS scene will be acquired between June and August, 2000

Methods

Geometric correction: TM and MODIS data will be geometrically corrected with a rubber sheet approach using ground control points collected from 1:200,000 topographic maps. The satellite data will be resampled using a nearest neighbor resampling technique.

Atmospheric correction: The 6S atmospheric code (Vermote et al., 1997) will be used along with a physically-based radiometric correction model (Sandmeier and Itten, 1997) to correct atmospheric influences. Aerosol optical thickness data will be derived from a Cimel sunphotometer installed at a forest research site of the Sukachev Institute and will be used as the main input parameter to 6S. Other atmospheric conditions will be selected from standard atmospheric profiles provided in 6S.

Overlaying ground and satellite data: Both ground LAI and satellite-derived LAI data will be included in a GIS. The geographical reference of the ground LAI measurement will be accurate to approximately 200m since the GPS unit used in the field will be operated in non-differential mode. The accuracy of the georectification of the TM data is subject to inadequacies in the topographic maps and the quality of the ground control points. To remove some of these geometrical uncertainties, we will reduce the original site dimension of 3km x 3km to 2km x 2km by removing a fringe of 500m along each edge of the test sites. By this method, the geographical location of ground measurements and satellite data should better correspond. A 2km x 2km test site corresponds to 4 MODIS pixels of 1-km size and 4489 TM pixels of 30-m pixel size.

Analysis

For each test site the atmospherically and geometrically corrected satellite data will be used to derive NDVI. Then, for each chronosequence (fir/spruce and larch) and replicate, the relationship between NDVI and LAI will be established using LAI data acquired within the framework of Segment I. Uncertainties in the relationship between NDVI and LAI will be characterized with error bars derived from the standard deviations of the data for the test site areas (Fig. 2). In 1999 only TM data for the fir/spruce site will be available for analysis. In year 2000 both TM and MODIS data will be investigated for the fir/spruce and for the larch chronosequences (with replicates).
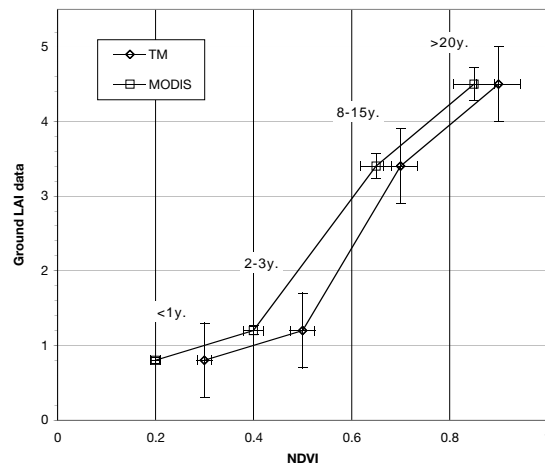

Fig. 2: *Example for presenting the relationship between NDVI derived from MODIS and TM satellite data and ground LAI measurements for four post-fire stand age sites (and replicates). Error bars will represent standard deviations in ground LAI measurements and NDVI data.*

The relationships between NDVI and LAI will be established for each species type and for both satellite systems. Using this relationship, LAI data from ground measurements will be compared with satellite derived LAI for various cases: TM and MODIS data, fir/spruce and larch species types, and primary and replicate sites (Fig. 3).
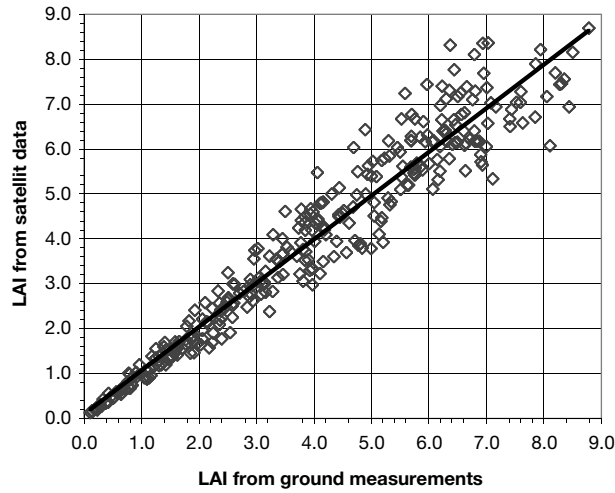
Fig. 3: *Example for presenting the relationship between LAI derived from MODIS and TM satellite data and ground LAI measurements.*

Based on the relationship between NDVI and ground LAI, LAI will be derived from the satellite data for the total overlaying area of MODIS and TM scenes for each species type and for both satellite systems. Images showing the differences between MODIS and TM LAI will be produced and analyzed. For this purpose, MODIS data will be resampled to the pixel size of TM, and LAI will be qualitatively and quantitatively compared for corresponding areas in each satellite scene (Fig. 4). For each MODIS pixel of 1km x 1km, the average and standard deviation of LAI of the corresponding TM pixels will be calculated. In 1999, MODIS data will be simulated by aggregating TM data to 1km pixel size.

The interpretation of the relationship between remotely sensed LAI and ground LAI data will be enhanced by including ground spectroradiometer measurements of the forest understory.
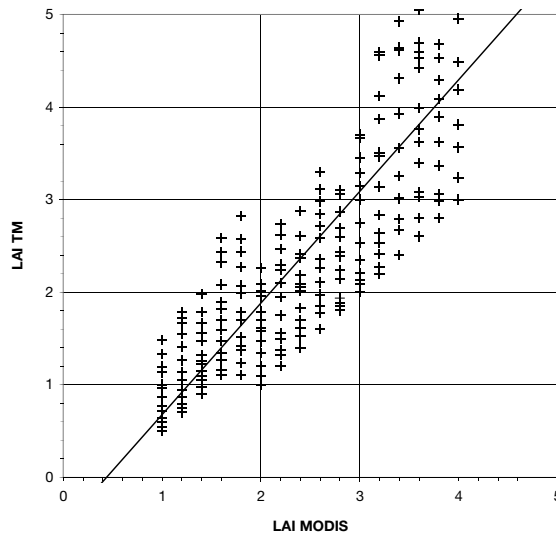

Fig. 4: *Example of a comparison between LAI derived from MODIS and TM data. For each MODIS pixel of 1kmx1km, the LAI will be plotted versus the corresponding data derived from TM.*

B. Explorative Methodologies

Goals

- Investigate the potential of BRDF data for improving LAI derivation with remote sensing data
- Establish the relationship between spectral BRDF effects and LAI for Siberian boreal forests

Scientific Questions

- What is the relationship between remotely sensed spectral BRDF effects and ground LAI measurements?

Data

- Historical POLDER scenes (level 2, directional parameters, 6km x 6km pixel size resolution, principal plane) acquired between November 1996 and June 1997 under cloud-free and clear-sky conditions will be used to investigate the spectral BRDF characteristics of the test sites
- 1 MISR scene will be acquired between June and August, 2000
- 1 new POLDER scene will be acquired

Methods

Geometric correction: If POLDER and/or MISR data are not geometrically corrected (level 2 products), we will perform the same geocoding procedure followed for the TM and MODIS data (described in Segment II.A).

Atmospheric correction: If POLDER and/or MISR data are not atmospherically corrected (level 2 products), we will perform the same radiometric correction followed for the TM and MODIS data (described in Segment II.A).

Anisotropy Indices: In order to analyze the spectral variability of BRDF effects and its relationship to LAI, two indices will be used: the anisotropy index (ANIX) and the normalized difference anisotropy index (NDAX). ANIX is defined as the ratio of maximum (R_{max}) and minimum (R_{min}) bidirectional reflectance factors per spectral band in the solar principal (or defined azimuthal) plane (Sandmeier et al., 1998; Sandmeier and Deering, 1999a):

$$\text{ANIX}(\lambda, \theta_i) = \frac{R_{max}(\lambda)}{R_{min}(\lambda)} \quad [\text{dimensionless}]$$

NDAX is a surrogate for the spectral variability of BRDF effects. It is derived similarly to the normalized difference vegetation index (NDVI) from a red (maximum BRDF effects) and a near-infrared (minimum BRDF effects) band but uses ANIX rather than nadir reflectance data (Sandmeier and Deering, 1999b):

$$\text{NDAX}(\theta_i) \ = \ \frac{\text{ANIX}_{red}(\theta_i) - \text{ANIX}_{nir}(\theta_i)}{\text{ANIX}_{red}(\theta_i) + \text{ANIX}_{nir}(\theta_i)}$$

In order to compare ANIX and NDAX data acquired in various azimuth planes and under different solar zenith angles, a suitable BRDF model will be incorporated such as the Rahman-Pinty-Verstrate model (Rahman et al., 1993) or the 4-scale model (Chen and Leblanc, 1997). The model will be fitted to ANIX and NDAX derived from POLDER and MISR satellite data using standard simplex procedures. Then, the model will be used to produce ANIX and NDAX data that are consistent in terms of azimuth plane and solar zenith angle conditions.

Analysis

For both species types (fir/spruce and larch) the relationship between the spectral BRDF characteristics and LAI for the four post-fire stages will be investigated in three different ways: (1) bidirectional reflectance characteristics in the principal plane, (2) spectral ANIX, and (3) NDAX. Both POLDER and MISR data acquired close to the principal plane will be used. Examples for results anticipated from the analysis planned are demonstrated in Figs. 5-7. The data presented in these figures are actual data acquired with the advanced solid-state array spectroradiometer (ASAS) for three different LAIs at Konza tallgrass prairie sites.

Results from the explorative and conventional methodologies will be evaluated in regard to the sensitivity and linearity of NDVI, ANIX and NDAX to LAI, and recommendations for LAI derivation from satellite data will be made.
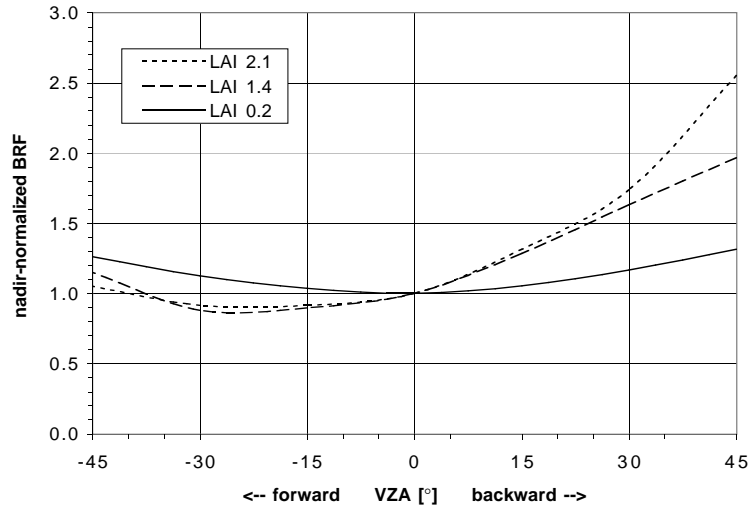
Fig. 5: *Example for analyzing the relationship between BRDF effects and LAI. Nadir-normalized bidirectional reflectance factors for Konza tallgrass prairie are presented for three different LAIs acquired with ASAS during FIFE.*
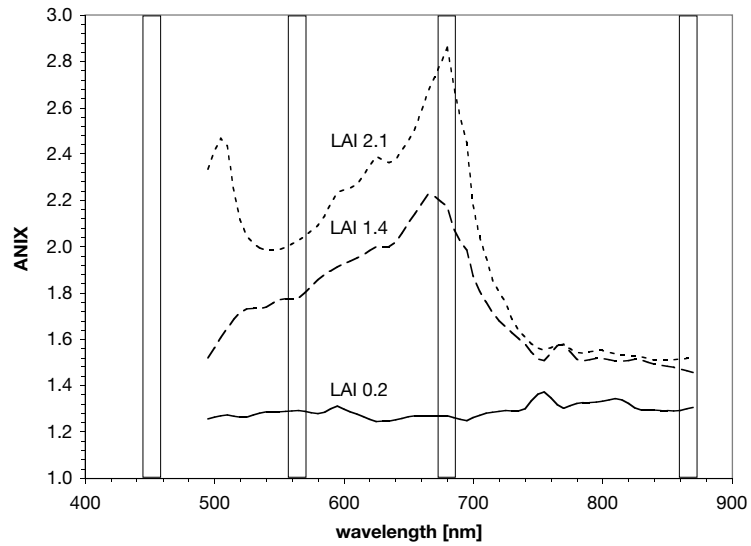

Fig. 6: *Example for analyzing the relationship between spectral ANIX data and LAI. ANIX data for Konza tallgrass prairie are presented for three different LAIs acquired with ASAS during FIFE. In our study, the spectral resolution of ANIX will be limited to the four MISR bands shown in rectangles and to the POLDER bands.*
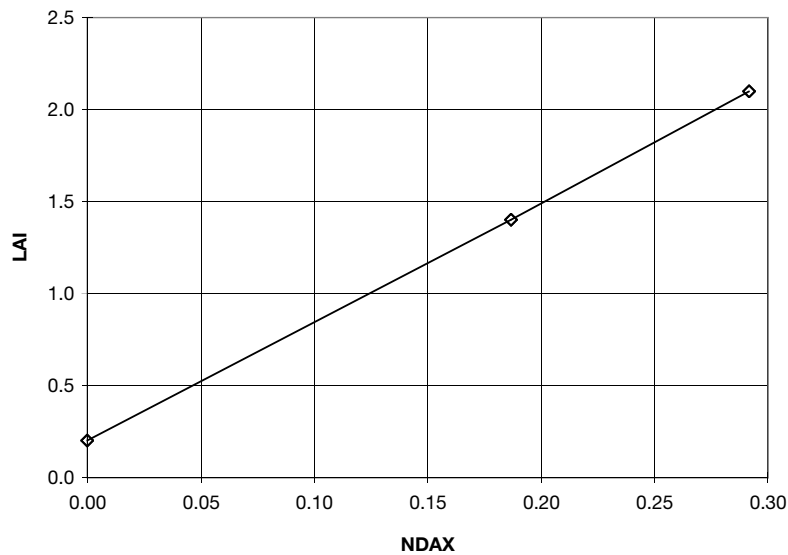
Fig. 7: *Example for analyzing the relationship between LAI and NDAX. LAI is plotted versus NDAX data for Konza tallgrass prairie for three different LAIs derived from ASAS data acquired during FIFE.*

Segment III – LAI Modeling

Goals

- Simulate LAI using the Biome-BGC ecosystem model at the plot and site levels
- Produce LAI maps using Biome-BGC to simulate a broader area of the Krasnoyarsk region

Scientific Questions

- Can the model simulate changes in LAI across the chronosequence of post-fire stands?
- How well does the simulated LAI correspond to the direct, optical, and satellite derived LAI?
- How well does simulated LAI compare to MODIS Land Validation (MODLAND) LAI?

Instrumentation/Material

- Meteorological station
- Soil temperature sensors
- Soil moisture sensors
- Litter screens
- Soil auger
- Trowels

- Flagging material
- Site markers
- Sample jars and bags

Data

- Data required to parameterize the Biome-BGC model will be collected from field measurements and from the literature.

Methods

Model Parameterization

A number of site-specific characteristics are required for successful simulation of the study area using the Biome-BGC model. These characteristics include daily drivers, the fractional land cover, and ecophysiological constants. The parameters and variables that we will collect as part of our study are listed in Table 1. The remaining information necessary to parameterize the model is listed in Table 2 and will be obtained from the literature.

We will collect the measurements identified in Table 1 during the field campaign and with dataloggers set up at the sites. In the summer of 1999, we will work toward model parameterization of one forest type, either spruce or fir. Daily weather data will be obtained from a meteorological station that will be sited in close proximity to the study sites (not more than 25 km from any one site). The meteorological station will have instrumentation to measure air temperature, precipitation, relative humidity, radiation, day length, vapor pressure, and snow depth. At each site, soil temperature and soil moisture sensors will be installed at depths of 10 cm and 25-50 cm respectively. Live vegetation will be collected from each canopy layer and age class for carbon and nitrogen determination. Annual litter production will be collected and litter will be analyzed for carbon, nitrogen, and percent lignin. Soil samples for carbon and nitrogen will be taken at a depth of 10-20 cm. Soil depth will be recorded, and analyses of soil texture and water content will be completed. In 2000, identical measurements will be collected in larch.

Modeling Exercises

Upon completion of initial model parameterization using the literature and field data, a series of spinup runs will be conducted to test sensitivity of the parameterization to various mortality rates from fire and non-fire sources. Once a reasonable fire regime is achieved, simulations of the Siberian boreal forest will be run up to the age of the oldest post-fire stand in our chronosequence. Predictions for parameters measured during the field campaigns will also be generated as a form of model validation. Parameters of interest will include: vegetation, litter and soil carbon; soil water; and leaf NPP (annual leaf litterfall).

Simulations will be accomplished at the plot scale (25m x 25m). Extrapolation of LAI to site and regional coverage of species will be completed through the use of GIS.

Analysis

We will compare values of LAI simulated for each post-fire stand age to the corresponding LAI derived from optical and direct methods in Segment I and from satellite data (Landsat-7 ETM, MODIS, POLDER, MISR) in Segment II. Simulated values for additional parameters such as vegetation, litter, and soil carbon; soil water; and leaf net primary production will also be compared to field measurements.

Table 1. *Measurements to be collected during field campaigns. Frequency refers to an individual plot.*

MEASUREMENT	FREQUENCY
Meteorological	
Temperature (air, soil)	Daily
Precipitation	Daily
Solar radiation (400nm-1100nm and 280-2800nm)	Daily
Humidity	Daily
Day-length	Daily
Vapor pressure	Daily
Snowpack depth	Daily
Vegetation	
Specific leaf area	Point
Age and annual growth increment	Point
Leaf C:N (live)	Point
Vegetation carbon	Point
Leaf litterfall (leaf NPP)	Monthly (growing season)
Leaf litter C:N	Monthly (growing season)
Leaf litter fractions (% labile, % cellulose, % lignin)	Monthly (growing season)
Litter carbon	Monthly (growing season)
Soil	
Soil carbon	Point
Soil water content	Monthly (growing season)
Soil water potential	Daily
Soil texture	Point
Soil depth	Point

Table 2. *Parameters and variables needed for model parameterization and validation that will be obtained from literature.*

MEASUREMENT	POTENTIAL SOURCE
Leaf longevity	Literature
Fire frequency, size, and intensity	Literature
Non-fire mortality rates	Literature
Leaf phenology (primarily date of new leaf growth)	Literature
Ratio of new leaf growth/new stem growth	Literature
Maximum and minimum stomatal conductance for water vapor	IRGA; E.D. Schulze

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